beam could be amplitude modulated, allowing for multiplexed detection of separate fiducial marks with a single photosensitive device via lock-in detection. The laser could be pulsed.

[0034] For instance, the dimensional position of the sample could be determined by scanning the lasers rapidly in x and y across a fiducial mark. The atomic force microscope tip position could then be determined by moving the laser to the vicinity of the tip and scanning the laser again in x and y to determine the tip position. This pair of measurements yields a delta x and delta y corresponding to the distance between the fiducial mark in the sample and the tip position determined in close proximity in time. This process is redone after tip exchange but this time finding the sample's fiducial mark and then setting the laser position to the predetermined delta x and delta y. The atomic force microscope's tip position would then be scanning mechanically until it was aligned to the laser and then lowered down to engage the sample. The converse procedure of scanning the sample instead of the tip would also work.

[0035] In addition, while a single laser beam can be used and preferably split by a beam splitter for multiple structure alignment and stabilization, in the case of two structure stabilization, at least one light beam could be independently steered (e.g., via a piezoelectric transducer (PZT) mirror, acousto-optic modulator, 2D translation lens, galvanometer mirror). Alternatively, for two structure stabilization with both structures mounted to independent translation stages, neither laser beam need be steered.

[0036] The invention is not limited to laser light, as coherent light can be substituted in place of a laser.

[0037] According to the present invention, a method for stabilization of one or more structures relative to another one or more structures includes using fiducial marks that are embedded in the structure or otherwise firmly coupled to the sample. A fiducial mark is not required if the structure possesses an inherent property that interacts with light to act as though it is a fiducial mark, for example, in a lens or a rough surface. The fiducial mark or feature/structure possessing the inherent property are required to scatter a detectable amount of incident light. For example, if a sample and lens are two structures being aligned, then the sample has a fiducial mark embedded in it, and the lens by its nature does not need a fiducial mark. In the case of stabilizing an atomic force microscope tip to the sample, there are three structures (the sample, atomic force microscope tip, and lens) to be stabilized. The sample has a fiducial mark, the lens does not, and the atomic force microscope tip may or may not act as a fiducial mark. Then the sample and atomic force microscope tip are stabilized relative to the lens.

[0038] Alternatively, when the structure is a lens, a focusing of incident light occurs. Thus, in the case of a lens, the focusing of incident light from at least a portion thereof is generally inherent and normally does not require a purposely made fiducial mark. In all of these cases one or more fiducial marks can be an integral part of the substrate surface.

[0039] The ability to perform registered tip exchange with nanoscale precision and repeatability at more than one local region (~100×100 μm) separated by arbitrarily large distances would be highly beneficial. With the present laser-based coordinate system and an array of fiducial marks, the stage can be maneuvered over large lateral distances (e.g., ~1-100 cm) relative to the tip, allowing the same nanoscale feature to be revisited by indexing off a nearby fiducial mark (e.g., two fiducial marks down, one fiducial mark to the right, and then a local motion outlined in FIG. **6**). Further, the tip itself can be replaced (e.g., if it is worn or broken), and a new tip can be returned to the same nanoscale feature by aligning the tip to its stationary detection laser. This process can be repeated at different locations on the substrate or sample, allowing for registered tip exchange with nanoscale precision at different locations separated by arbitrarily large distances.

[0040] The fiducials can comprise silicon posts, as disclosed in King, G. M., Carter, A. R., Churnside, A. B., Eberle, L. S. & Perkins, T. T. *Ultrastable atomic force microscopy: atomic-scale lateral stability and registration in ambient condition*. Nano Lett. 9, 1451-1456 (2009), incorporated herein by reference. The material composition and geometry of the fiducial mark is variable. All that is required is that the mark scatters a detectable amount of incident light. Examples of such marks include about 100-1000 nm tall, about 100-1000 nm diameter SiO_2 posts, lower profile about 10 nm tall, about 100 nm Au or Si disks, negative features such as about 100 nm deep, about 100 nm pits and even scanning microscope probe tips.

[0041] Back-scattered light from the sample and tip is separated and collected by a photosensitive device. Preferred photosensitive devices can include a quadrant photo diode, a position sensitive detector, and a charge coupled device. The photosensitive device(s) outputs an electronic signal which reveals the dimensional position of each fiducial mark and, hence, the dimensional position of each structure. These signals are used in a feedback loop which can keep the differential position stable, or to precisely scan the position between the two structures. The bandwidth of the stabilization is restricted by the time it takes to close the feedback loop. In practice, this is often limited by mechanical resonances (~1 kHz) of the positioning stage.

[0042] Referring to FIG. **2**, there is a photosensitive device, which receives scattered light from either tip, laser or both and provides a signal to a feedback algorithm or processor and a controller, which serve as a feedback system to control the arrangement of the positioner, so that, for example, the distance "d" is maintained between the structures. The distance may be maintained for a predetermined period of time (time interval).

[0043] In a preferred embodiment, the back-scattered signals can be efficiently separated from the inward-propagating lasers by an optical isolator formed by a polarizing beam splitter (PBS) and a quarter waveplate (λ/4). Next, a dichroic mirror separates the signals onto two different quadrant photodiodes (QPDs). Movement of the fiducial mark in x and y relative to the detector beam causes a corresponding change in the distribution of light on the quadrant photodiode (QPD). Thus, the difference between the left and right halves measures the x signal, and the difference between the top and bottom halves yields the y signal. Vertical motion (z) is deduced by the sum signal, which is the total light falling upon the four quadrants of the quadrant photodiode. The resulting quadrant photodiode voltages can be amplified using custom built electronics and digitized. The sample's and tip's positions are preferably controlled via a feedback loop using a precision positioner. For force sensing, we reflected a 785 nm laser off the backside of the atomic force microscope cantilever and detected its deflection with a quadrant photodiode using a standard optical lever arm, as described in Meyer, G. & Amer, N. M. *Novel Optical*